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The relationship of ultrasonic and mechanical properties of human nuclear cataract. A pilot study

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Introduction

Cataract is the leading cause of blindness worldwide and cataract extractions account for the majority of all ophthalmic procedures. Cataract is predominantly an age-related disease, and with increased lifetime, the frequency of cataract surgery will increase. Cataract surgery has become the most frequent operative procedure in our society. The continuous improvement of surgical techniques enables the operative procedure to become safer and the postoperative results better. Phacoemulsification is a cataract surgery technique during which the eye lens nucleus is carefully dissected by an oscillating hollow needle simultaneously serving as a suction line for lens fragments. The success of this procedure depends greatly on the mechanical properties of the lens nucleus. Phacoemulsification of a hard nucleus is associated with an increase in phacoemulsification time and power and therefore dissipated energy. Increased irrigation time may affect corneal endothelial cells, and movement of the lens during sculpting can result in stress on the zonules and the capsule. Some authors consider a hard lens nucleus to be a relative contraindication to phacoemulsification, as increased surgical manipulation could contribute to higher morbidity [1].

It is known that stiffness of lens nucleus is associated with the clinical appearance of brunescence and advancing age. Alterations in the nature and concentration of proteins, lens fibre compaction and other biochemical changes may all be contributing factors towards increased stiffness [2].

Lens stiffness may depend on many factors such as aging, degree and extend of cataract formation, which are interlinked with changes in the nature of the proteins, compactness of the fibers and other biochemical changes [3]. Hard lens nucleus often causes various surgical difficulties especially while performing phacoemulsification. If it could be possible to measure the stiffness of lens nucleus pre-operatively it would help to permit proper surgical planning and successful cataract extraction.

The aim of the pilot study was to investigate experimentally the relationship between the clinical appearance, ultrasonic and mechanical characteristics of nucleus cataract.

Materials and methods

An experimental study in order to assess the new method and new device of lens stiffness measuring was performed with 10 lenses of enucleated dogs' eyes. We compared the ultrasound attenuation coefficient and the stiffness of extracted lens. Then in our clinical study we analized a human nuclear cataract. The sample consisted of 4 individuals (4 eyes) who were scheduled for cataract extraction in Eye clinic of Kaunas University of Medicine. Patients age varied from 73 to 85 years of age, 1 of them was female, 3 – males.

The relationship of parameters of human nuclear cataract has been evaluated using optical, ultrasonic and mechanical methods.

<u>Optical method</u>

The patients received an initial ophthalmic examination with the slit lamp. Those who had clinically significant changes in the lens nucleus were included into the study. Patients were excluded from participation if they had any other ocular diseases such as glaucoma or clinically significant diabetic retinopathy. Patients with prior corneal or anterior segment surgery or corneal scars which would interfere with visualization or photography of the anterior segment were also excluded. In order to quantify lens opacities we used LOCS III classification system. Nuclear opacities and nuclear color were assessed. Slit-lamp photographs of the lenses after pupil dilatation were performed using digital slit lamp Topcon SL 8Z, images stored in the PC.

<u>Ultrasonic method</u>

We used A scan for in-vivo examination of nuclear cataract. A-scan examination has been performed by *Mentor*™ A/B ultrasonic imaging system using 7 MHz A-mode probe. Radio frequency (RF) echo signals from lens were digitized by TEKTRONIX 220 oscilloscope at the sampling rate 250 MHz and 8 bit amplitude resolution, bandwidth for analog signal - 100 MHz. The echo signals from the anterior and posterior interfaces of the lens were cute down by the time windows. To get the correct RF signals from the eye lens the signals sinchronizator for oscilloscope has been used.

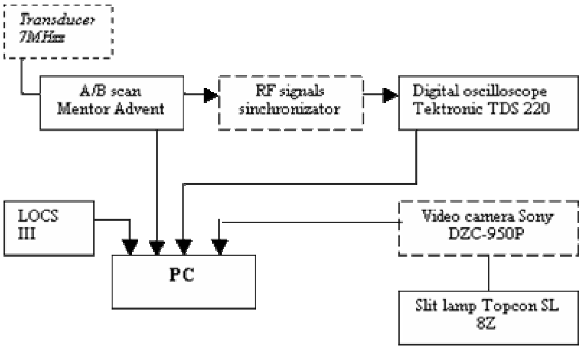

Fig.1. **The scheme of used methods for determination and parametrization of human nuclear cataract**

After optical and ultrasound examinations of the lens, the lens stiffness was assessed by the mechanical measuring system constructed in Kaunas University of Technology.

<u>Mechanical method</u>

A new measurement system was developed to determine the mechanical properties of extracted lens. Hereby, a force was applied to the specimen to determine their mechanical response and the resultant of displacement has been measured. Stiffness and ultimate strength of the material has been determined by measuring the relationship between lens displacement *D* (mm) and applied force *F* (N) (weight from 2 to 140g)).

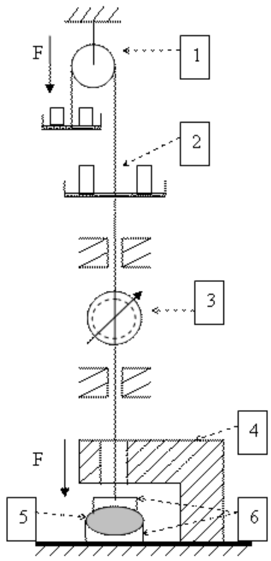

Fig. 2. **The scheme of mechanical measuring method of the lens: (1- balancing system, 2 - weights, 3 – micrometer, 4 – the stand of organic glass, 5 - lens, 6 – lens holders (upper- R=3.6 mm and bottom- R=7.2mm))**

First, we examined experimentally 10 extracted lenses of enucleated dogs' eyes in order to assess the new method and device of lens stiffness measuring and to evaluate the relationship between lens stiffness and ultrasound attenuation coefficient.

With the purpose to get the correct ultrasonic RF signals, enucleated dogs eyes were put into the special locking device (Fig. 3). This device is necessary for the accurate and fixed position of transducer to the object, and to avoid deformation and changes of intraocular pressure.

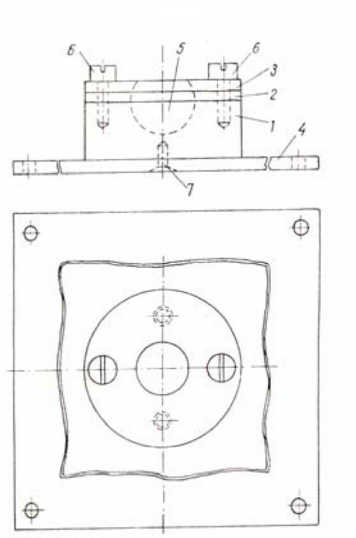

Fig.3. **Locking device for fixing of the enucleated eye**: **(1 – the body made of organic glass, 2 – a liner of rubber, 3 – a plate of organic glass, 4 – a fixing plane, 5 – a gouge for putting the enucleated eye, 6 – screws, 7 – a screw for fixing the plane).**

Results

The attenuation coefficient has been calculated using spectral difference measurement method [10, 11].

Table 1. **Ultrasonic and mechanical parameters of dogs' lenses**

Dogs lens	Ultrasound attenuation coefficient range, dB/(cm·MHz)	Lens stiffness at 140g, (N/mm)
1	1.802	0.2749
2	1.5369	0.3437
3	2.5608	1.1852
4	2.5532	1.5275
5	1.3032	0.2644
6	3.8704	1.1854
7	3.3693	1.1553
8	1.1221	0.3055
9	5.5482	3.7157
10	0.9167	0.237

Dogs eye lenses showed an elastic mechanical behavior. Mechanical and ultrasonic properties correlate significantly – r=0.92, p<0.01. The mean of ultrasound attenuation coefficient of dogs lens is β=2.46±1.04 dB/(cm·MHz), the mean of lens stiffness is 1.02±0.77 N/mm. The linear approximation of data shown in Fig.4

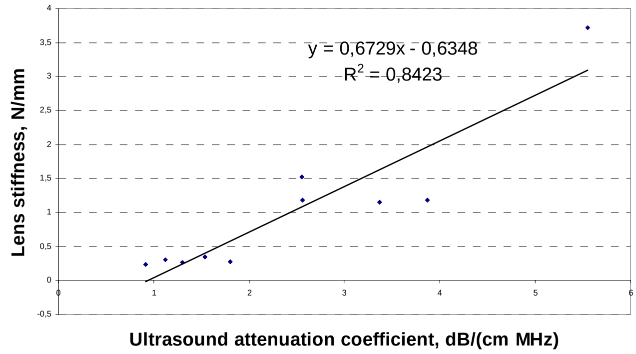

Fig. 4. **The linear approximation of data**

We analysed the clinical appearance, mechanical and ultrasonic properties of human nuclear cataract and found that ultrasound attenuation coefficient is significantly higher in human nuclear cataractous lenses (Table 2), the mean of attenuation coefficient β=11.63±1.04 dB/(cm·MHz) compared with non-cataractous lenses, the mean of attenuation coefficient β=5.88±1.00 dB/(cm·MHz) [10], the mean of lens stiffness is 4.61±1.66 N/mm. The lens stiffness is proportional to the ratio of displacement and applied force of penetration ($\Delta F/\Delta D$) (Fig. 3).

Ultrasound attenuation and lens stiffness were significantly correlated – r=0.99, p<0.05. Attenuation increased in harder lenses (Table 2). Stiffness and strength increase with increasing nuclear coloration. Human eye nucleus lens showed a plastic mechanical behavior. Measurement of stiffness was reproducible after 8 loading cycles with 30 sec time between them, when a steady-state was reached. The lens stiffness was calculated at 140 g – the maximum force.

Table 2. **Diagnostic optical, ultrasonic and mechanical parameters of human nuclear cataract**

Patient	Subjective nuclear maturity grade	Lens opacity according LOCS III classification system	Ultrasound attenuation coefficient range, dB/(cm MHz)	Lens stiffness at 140g, (N/mm)
Patient 1	immature	NO 4.3 NC 6.1	11.0284	4.4348
Patient 2	immature	NO 5 NC 5.4	10.7962	4.5826
Patient 3	immature	NO 5.5 NC 6	16.6508	5.9774
Patient 4	immature	NO 2.9 NC 4	8,0637	3.437
Patient 5	Control (non-cataractous)	NO 1,6. NC 0,8	2.0564	-

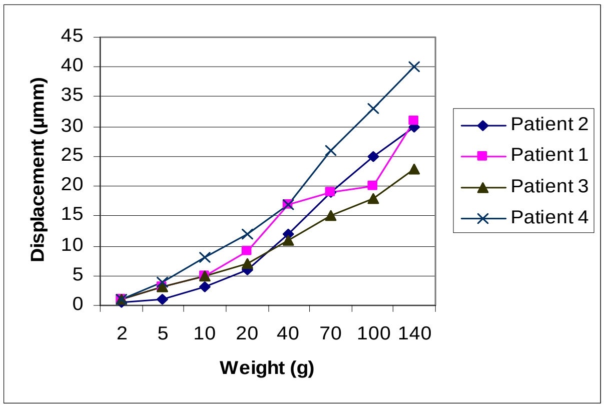

Fig. 5. **The results of human nuclear lens stiffness measurement - the relationship of displacement and weight**

The linear approximation of data of human nuclear cataract shown in Fig.6.

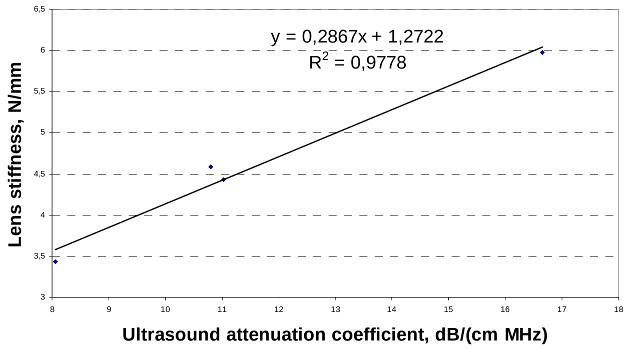

Fig. 6. **The linear approximation of data of human nuclear cataract**.

Discussion

Stiffness of cataractous lenses is one of the major factors influencing the suitability of a patient for phacoemulcification. Age and nuclear color have been shown to be good clinical markers of lens stiffness, but there is a need of more quantitative and objective examination method. Noninvasive methods, such as ultrasonography, that are based on tissue – density properties have the potential to provide additional useful information. Oguchi and coauthors studied the influence of the crystalline lens on the ultrasonic field and found that the lens has absorbing, scattering and deviating effects on the propagating sound beam. In a study of ultrasound appearance of senile lens changes the correlation between the amount of opacity in the anterior cortex and nucleus with abnormal ultrasound patterns was found [12]. Sugata Y. and coauthors [13] examined normal and cataract lenses and suggested the possibility of diagnosing cataract by measuring the attenuation characteristics of the lens.

The success of operation depends on mechanical properties of nucleus lens. It is very important preoperatively evaluate the lens nucleus stiffness for the right tactics and time of operation. It is difficult and complicated to make ultrasound emulsification of hard lens nucleus. Due to this emulsification time and operation term getting longer and the risk of postoperative complications can increase.

Tabandeh H. and coauthors found the relationship between ultrasound wave attenuation and hardness of the crystalline lens where lens hardness was measured by specially designed lens guillotine. It was found that attenuation and hardness were significantly correlated, attenuation increased in harder lenses [2].

Chuprov and coauthors [4] evaluated mechanical and ultrasonic characteristics of the lens nucleus, where ultrasonic examination was performed with Humphrey's A/B scanning and the nucleus solidity was measured by microhardness meter. Correlation between the findings of ultrasonic scanning and mechanical solidity was direct and strong. The proposed ultrasonic method can be used in cataract surgery for evaluating the solidity of the lens nucleus before surgery.

Heyworth and coauthors [5] investigated the relationship between the clinical appearance of cataracts and their hardness, where lens hardness was evaluated using an automated lens guillotine. The findings confirmed clinical suspicions and enable surgeons to make more objective analysis of hardness prior to phacoemulsification.

Pau H. [6] using a fine conical probe and a miniature dynamometer for hardness measurement, the resistance to penetration (stiffness) of different colored lenses and different forms of „senile" cataract measured. Increasing pathological brown or black coloration of the lens nucleus is related to maximum hardness.

Czygan G. and coauthors [7] investigated mechanical and optical properties of senile cataractous human eye lens nuclei using a special mechanical measurement system where a forse was applied to the specimen. Stiffness and strenght increase with increasing nuclear coloration. It is concluded that optical properties can be useful to assess the mechanical response of cataractous eye lens nuclei.

Hu C. and coauthors [8] determined the nuclear hardness and associated factors of age-related cataract, for hardness measurement using a fine conical probe and dynamometer, the resistance to penetration different lens layers was transferred to an electric signal and recorded. Multivariate analysis of the data showed that 85% of the variation in hardness could be explained in terms of color and opacity.

Smith and coauthors [9] evaluated the relantionship between lens hardness and clinical classification of nuclear cataracts using a special caliper incorporating a strain gauge, enabling the derivation of a graph of nuclear compression (D(mm) against applied force (F(N)). There was found a relationship between the LOCS III clinical classification of nuclear cataracts and mechanical compression characteristics of the cataractous lens.

This study documents a relationship between the clinical appearance, ultrasound attenuation and lens stiffness. Changes in the lens structure associated with cataract formation, aging, and lens hardening influence ultrasound wave characteristics. In cataractous lens, increased protein aggregation and inner fiber compaction contribute to the hardening of the lens and increase attenuation of the ultrasound waves. By calculating the ultrasound attenuation coefficient there is a possibility to measure lens stiffness in vivo.

Mechanical properties of the cataractous lens are one of the major factors influencing the suitability of a patient for phacoemulsification. Surgeons should be able to estimate hardness when choosing patients to this method of cataract extraction.

These methods are valuable when making the prognosis of the operation term and even operation methodics. Methods for in vivo evaluation of lens hardness and its relationship with the clinical appearance and ultrasound attenuation have clinical and research applications and must be further developed.

Conclusions

1. Lens opacities according LOCS III classification system correlated with ultrasoud attenuation coefficient.
2. The ultrasonic and mechanical properties of lens nucleus correlate significantly.
3. Ultrasonic properties can be used to assess the mechanical responce of cataractous eye lens nuclei.
4. The evidence of relationship between lens stiffness of human nuclear cataractous lens and ultrasound attenuation could be a diagnostic decision support with the purpose to choose the right operation tactics and to avoid the postoperative complications.

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Ryšys tarp ultragarsinių ir mechaninių žmogaus akies lęšio branduolio kataraktos savybių. Bandomoji studija

Reziumė

Katarakta yra vyresnio amžiaus žmonių liga ir ilgėjant gyvenimo trukmei ja sergama dažniau ir operacijų atliekama daugiau. Tobulėjanti chirurginė technika įgalina saugiai atlikti intervencines procedūras ir tikėtis gerų pooperacinių rezultatų. Operacijos sėkmė priklauso nuo mechaninių lęšio branduolio savybių. Chirurginės taktikos ir trukmės parinkimui labai svarbu įvertinti lęšio branduolio kietumą prieš operaciją. Kietą lęšį sunku ultragarsu emulsifikuoti, dėl to pailgėja emulsifikacijos laikas, taip pat ir operacijos trukmė, didėja pooperacinių komplikacijų rizika. Darbo tikslas buvo įvertinti ultragarsines ir mechanines lęšio branduolio savybes, kurios padėtų neinvaziniu būdu nustatyti lęšio branduolio kietumą prieš operaciją. Lęšio drumstumo laipsnis buvo vertinamas pagal tarptautinę LOCS III klasifikacijos sistemą. Kietumo laipsnio optiškai (*in vivo*) nustatyti neįmanoma, todėl lęšis buvo tiriamas ultragarsine A sistema, fiksuojant dažninius radijo signalus ir apskaičiuojant ultragarso slopinimo koeficientą. Po operacijos pašalinti lęšiuko branduoliai tiriami šiam tikslui sukonstruotu lęšio deformacijos įvertinimo prietaisu. Įdiegiant naują lęšio kietumo įvertinimo metodiką į eksperimentą, pirmiausia buvo tiriama 10 šunų akių su skaidriais lęšiais. Nustačius tiesioginę priklausomybę tarp ultragarso slopinimo koeficiento ir lęšio branduolio kietumo, toliau tiriami žmogaus akies lęšio branduoliai. Lęšio kietumo *in vivo* įvertinimo metodai ir ryšys su klinikine kataraktos išraiška bei ultragarso slopinimu turi mokslinę ir praktinę reikšmę ir turi būti toliau tiriami.

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